A Geo-Archaeological Model of Holocene Landscape Development and its Implications for the Preservation of Archaeological Sites

Benjamin Ducke
Projekt Archäoprognose, Archaeological Heritage Management Brandenburg,
Wünsdorf 15838, Germany
benducke@compuserve.de

Abstract

This paper presents a geo-archaeological approach to estimating the potential state of preservation of archaeological sites in the Northern European Lowlands where the Holocene shaping of the landscape has been dominated by processes of soil erosion and deposition. Initiated by Neolithic settlers and constantly fuelled by agricultural land use, these processes have reached an unprecedented magnitude with the emergence of mechanized agriculture in the 20th century. Over time, as determined by topography and soil properties, protective soil layers are either removed (erosion), thereby exposing sites to an increased risk of being destroyed or built up (deposition), preserving the sites but making them hard to find. In recent years, geo-physical models have been developed that are both precise and easy to parameterize. With the help of these and the integration of archaeological data, it is possible to locate and assess the potential locations of eroded and covered sites. The work presented in this paper is partly derived from the author's M.A. thesis (Ducke 2002, in German language, yet unpublished) and is also part of "Projekt Archäoprognose Brandenburg" , a research project aiming to provide a complete predictive map for archaeological sites in the state of Brandenburg, North-eastern Germany (Müller and Kunow 2002; http://www.uni-bamberg.de/~ba5vf99/index.html).

Keywords: archaeological site management, geo-archaeology, erosion models, soil erosion/deposition, risk assessment.

Assessing the Invisible

It has been understood for some time, that archaeological research on a landscape scale must pay close attention to the intimate relationships between cultural sites and landscape development (e.g. Davidson 1985, Holliday 1992). This holds true for archaeological heritage management as well. Besides conserving visible monuments of our past, we must also strive to preserve the true, unseen extent of our cultural heritage as it lies buried in the ground, hidden from the senses of the archaeological prospector.[1]
Most obviously, it is the landscape's topography and the strength of the geomorphological processes of erosion and deposition that have shaped it which primarily determine the state of conservation of the embedded sites.
If the protective soil cover has been reduced by erosion, the archaeological site's remains will be exposed to human activities (ploughing, construction work), and can more or less be written off as 'destroyed'. On the other hand, sites that have spent the last millennia under a thick, protective cover of deposited soil, can be

expected to produce well preserved features. It would, therefore, be wise to have a firm understanding of the large scale development of a given landscape's topography. Knowing where to expect potentially well preserved (covered) sites provides important hints for the allocation of resources to places where time, money and research effort can be invested most profitably. The planning and conduction of rescue excavations in particular could benefit immensely from the additional information offered by a robust model of erosion/deposition (for simplicity: erosion model) as time and money for such work is usually very limited. In this context, one can speak of archaeological erosion risk assessment.

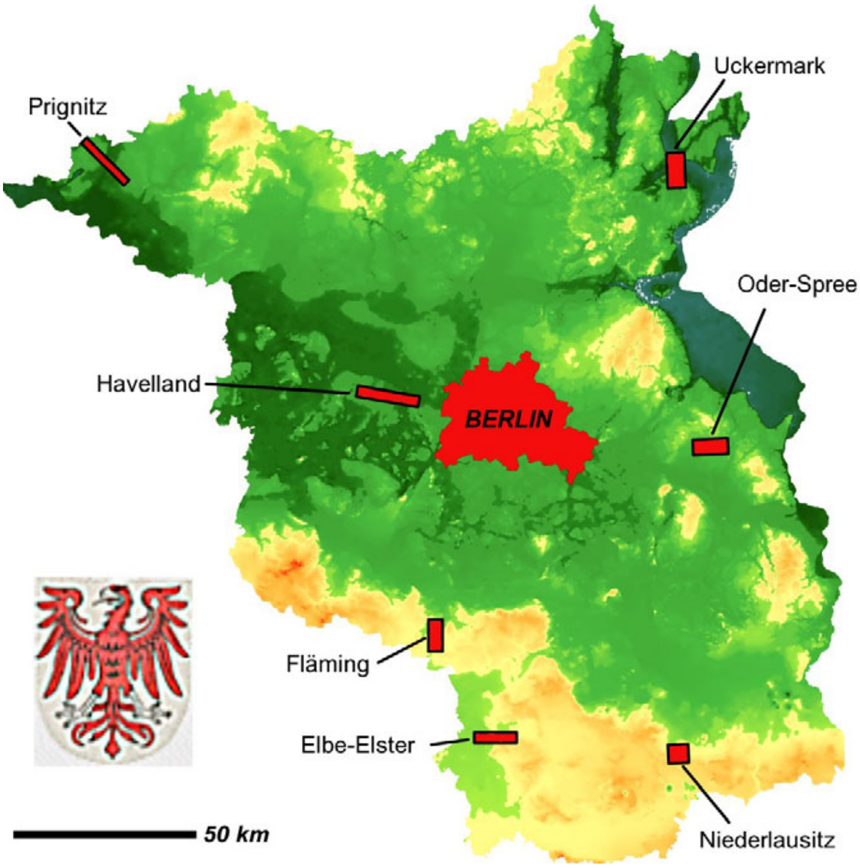

Fig. 1: The state of Brandenburg in North-eastern Germany. The study area discussed in this paper is designated "Havelland".

These considerations led to the design of the erosion model for holocene landscape development in the Northern European Lowlands presented in this paper that should be useful both as a tool to support archaeological assessment and resource allocation in heritage management, as well as to gain a better understanding of the history of human impact on the landscape. The geographical and archaeological data to support the research presented in this paper is taken from a study area west of the capital city Berlin in North-eastern Germany ("Havelland" in Fig. 1). With its extent of about 3 x 17.7 km, the region can be considered large enough to justify a landscape scale approach on a detail level of 10 x 10 m ground resolution. In a broader geographic perspective, the Havelland is a part of the Northern European Lowlands that extend from the Netherlands in the west to the largest part of Poland in the East.

Soil Erosion and Landscape Development

As far as the Northern European Lowlands are concerned, the most recent large scale shaping of the landscape by natural geological and geomorphological processes can be dated back to the final glacial phase of the last Ice Age ca. 12,000 years ago. The geological epoch that followed, the Holocene, has so far been one of stable geological conditions. Under natural conditions, the landscape forms that were created by the retreating glaciers would have survived until today. Archaeological sites could then be expected to lie uniformly buried under a relatively thin layer of fertile soil built up in place from decomposed organic remains. The fact that archaeological stratigraphies in the area under discussion usually display a much more complex, heterogeneous depositional pattern can mostly be attributed to direct human impact.

The European Plains as we perceive them today are much different in appearance from what they were like when the first farmers settled there in the 6th millennium BC. In fact, what we see is only a flattened, stripped, spatially homogenised reminiscence of the natural Holocene landscape (Fig. 2).

Fig. 2: A typical landscape in North-eastern Germany.

Claiming one patch of land after another for millennia in succession, the farmers of the Northern European Lowlands have been stripping the landscape of its natural cover, hacking, burning down and up-rooting the vegetation and replacing dense forests with open, unprotected agricultural fields. With the natural vegetation gone, there is nothing that could prevent the fertile, volatile cover of soil from being washed off and transported down the slopes by intense rain and from being blown away by the wind, whenever fields lie bare of crop. Over a certain period of time, this process, called soil erosion, invariably leads to a situation where the thin top layers of fertile soil become concentrated in locations that wrap around the bottom of the slopes while the larger up-hill areas are deprived of them. Overall, the result is severe soil degradation and a flattening of the landscape.

The archaeological literature abounds with stratigraphical and geomorphological observations that indicate events of disastrous erosion by water and wind. Some recent publications include examples from Central Europe such as Bork 1988, Jäger 1996, Semmel 1995, Saile 2001, Lozek and Jäger 1977, but also similar observations from virtually all other parts of the world (e.g. Sandor 1992, Verhagen 1996, Zeidler and Isaacson 2001). However, precise quantifications of the soil volumes involved are hard to find, discussion of the phenomenon itself is seldom given more room than a sidenote (for the study area, somewhat more elaborate discussions can be found in Fischer-Zuijkov 1998 and Krauskopf and Pasda 1999). Fortunately, some recent publications with geo-archaeological study cases from North-eastern Germany (Bork et al. 1998, Schatz 2000) have considerably alleviated the stand-still situation. These recent studies have shown:

1. In the area under study, soil erosion has been and still is the dominant geomorphological process.

2. Soil erosion started as soon as agriculture was introduced in the area under study. The problem was then never solved and stayed with us up until today (Rose 1996). Mankind still does not have a recipe to cope with it, so the geomorphological processes of erosion and deposition continue to alter the landscape.

3. The intensity of soil erosion processes has seen several dramatic peaks; provably in the iron age (ca. 8th century AD to 4th century BC) and in the 14th century BC. During these times, soil erosion was so massive that it made whole regions unsuitable for growing crops and led to the abandonment of settlements. In the de-populated areas, the soil system was given time to recover.

4. In the long term, soil erosion leads to a flattening of the landscape. Soil is washed down from the up-hill areas and deposited in the valleys, thereby reducing the total difference of height between the top and the bottom of any given slope profile.

Modelling Soil Erosion

If soil erosion were allowed to continue for ever, sooner or later the entire landscape would be a single flat plain without noticeable relief. Fortunately, as of today, we are not at that point. Although having been blurred, softened, and flattened by soil erosion, the landscape's relief still retains its ancient topographical properties. When studied on a large scale, it becomes apparent that the terrain still rises (although less steeply) and falls in the same places where it has done so 12,000 years ago.

It is possible, therefore, to model the movement of soil masses through the landscape in the past based on presently available data and from such a model learn about the locations of soil depositions that might still cover largely undisturbed archaeological sites in the landscape today.

1 Empirical Models

In our times, a need for assessment and - so it was hoped - management of large scale soil erosion risk first arose in the U.S.A. after the Second World War when it was realized that gigantic areas were subject to soil erosion (badlands) and that the situation was constantly getting worse (a prominent historical symbol for the total devastation of agricultural areas by wind erosion is the Dust Bowl of the Great Plains). For any counter-actions to be effectively deployed, however, a standard measure of erosion risk had first to be found.

This was achieved with the definition of the important geo-scientific parameters and their incorporation into the Universal Soil Loss Equation (USLE; Wischmeier and Smith 1960):

$$E = LS \times R \times C \times K \times P$$

In this equation, the net erosion rate E (measured in tons per acre and year) is calculated from five factors that quantify the impact of topography (LS), rain intensity (R), vegetation cover (C), soil erodibility (K) and preventive actions (P ; includes such things as contour ploughing and planting hedges as erosion barriers), respectively. Except for R, each of these factors has strong local variability and has to be empirically derived from field measurements.

Further work was required for the single most important factor - topography - to be adequately represented in the equation and resulted in the Revised Universal Soil Loss Equation (RUSLE; Renard et al. 1991). At this point, empirical soil erosion models were fully developed. Owing to several decades of practical usage, USLE-based models work well in real-world applications. Using geo-referenced USLE parameters in a GIS enables the user to calculate spatially precise predictions of erosion rates. Such a model does not, however, predict deposition - which makes it insufficient for archaeological purposes.

2 Process-based Models

The last decade has seen the emergence of refined erosion models, many of which go far beyond the mere practical needs of calculating erosion risk. Process-based models such as the Water Erosion Prediction Project (WEPP; see WEPP 2001) or the European Soil Erosion Model (Eurosem; Morgan et al. 1998) allow for detailed studies of the processes involved in erosion to gain a better understanding of landscape development. Projects like WEPP and EUROSEM strive to precisely model a multitude of interacting natural and anthropogenic processes. In this way they make precise predictions of erosion and deposition possible and at the same time propagate an insight understanding of the processes involved. With the CHILD (Channel Hillslope Integrated Landscape Development; see Tucker et al. 1999) project, there even exists a model that takes the whole of landscape evolution into account, including wind and water erosion, stream meandering and rainfall runoff.

While in theory being a superior research tool, the practical drawback of these models is that they require lots of difficult-to-obtain, precise quantifications for their numerous parameters. While it is possible - with some effort - to provide such high-quality parameters for an area of reasonably limited extent, coverage for a whole landscape easily becomes an insurmountable obstacle in archaeological reality. Therefore, models like WEPP and EUROSEM are used on a per-field basis rather than on a landscape scale. In the United States, the CHILD model has recently seen practical use in a geo-archaeological project much like in aims to the present paper's, but supported by far more generous scientific and financial resources (Zeidler and Isaacson 2001).

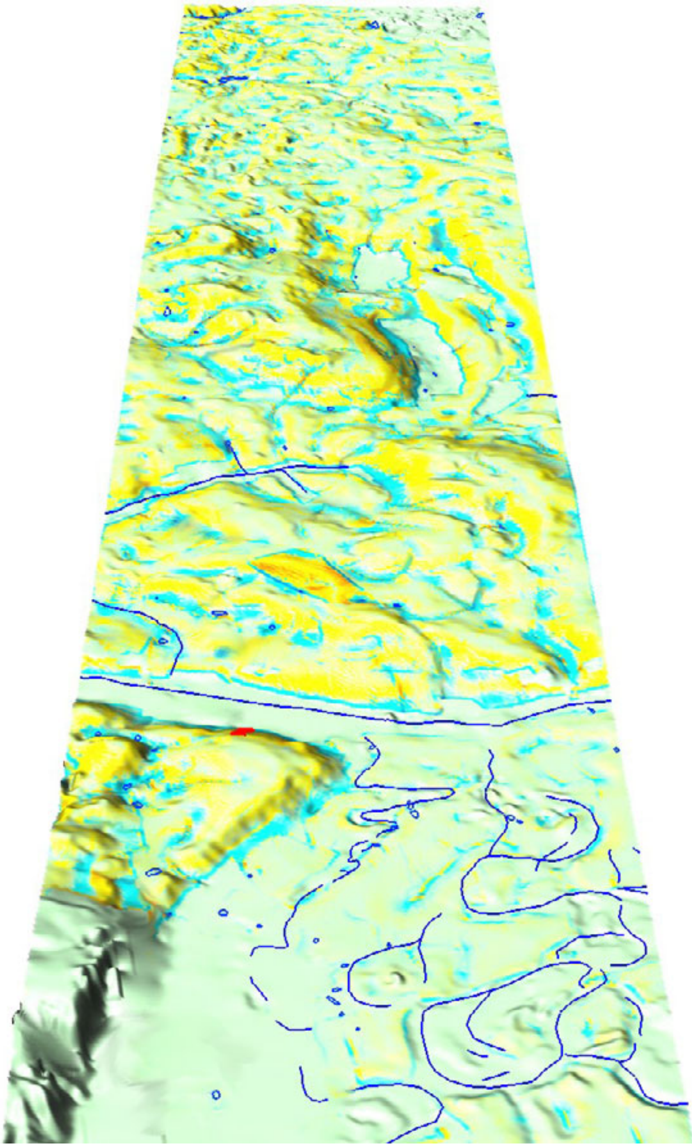

Fig. 3: USPED-based erosion/deposition model of the study area "Havelland". Orange to yellow colours indicate erosion, greenish to blue colours indicate deposition (observer facing roughly westward; shaded for better visualization; vertical exaggeration factor=10). The red area is the location of Dyrotz 37 (see section 5).

3 The USPED Model

An optimal model for archaeological erosion risk assessment would therefore combine easily accessible and robust parameters (USLE, RUSLE) with the predictive capabilities of a more advanced model (USPED, WEPP, CHILD). Fortunately, just such a model exists. USPED (Universal Stream Power Erosion Deposition) calculates rates of erosion and deposition according to a simple geo-physical model (based on original concepts by Moore and Burch 1986) that essentially replaces the LS factor of the USLE equation (see section 3.1).

USPED assumes a steady state overland water flow with uniform rainfall excess conditions. Steady state water flow can be expressed as a function of upslope contributing area per unit contour width which in turn can easily be calculated from a DEM. It is further assumed that the sediment flow rate is at the sediment transport capacity limit which can be approximated using a slope model derived from the DEM and the standard USLE parameters (see section 4.1). The net erosion/deposition rate is then estimated as divergence of sediment flow (Mitasova and Mitas 1999).

To understand the physical reasoning behind this approach, consider erosion/deposition as the opposing outcomes of a battle between two physical forces working in different directions: gravity, that pulls sediment particles down onto the surface and water flow that causes them to float down-hill. As soon as sediment particles are detached from the surface by the impact of rain drops (see Ellison 1944), they start to float soluted in a layer of water. At any point along their way, these particles can either settle down and form a colluvial deposition or float on further. Which of these two events occurs depends on whether gravity or water flow is stronger. In places with diverging flow and flat slope, the power of water flow drops below that of gravity and the sediment particles are attracted toward the surface where they are deposited. These places usually correspond with the broad, concave foot areas of the hill slopes.

USPED is easy to implement and makes use of the USLE parameters for local estimations of erosion/deposition rates. Instructions for several popular GIS platforms and an in-depth explanation of the mathematical methods have been compiled by Mitasova and Mitas (1999). Fig. 3 shows the result of applying a USPED-based erosion/deposition model to the study area.

Data Acquisition for Erosion Modelling

Armed with a high quality DEM and the USPED equation, the only thing missing are local quantifications for the remaining USLE parameters. For the area under study, there is no publicly available database from which they could be taken. The necessary values must therefore be derived from other sources.

1. Rainfall intensity (R) can be approximated from histograms of local rainfall capacity. For North-eastern Germany, the mean annual rainfall capacity is around 400-600 mm, resulting in a value for R of about $R=40$.

2. Vegetation cover (C) is a very complex parameter but can be roughly estimated using standard relations for vegetation classes (see Mitasova et al. 2001). For the area under study, values of $C=\{0.4, 0.004, 0.0005\}$ were used for fields, pastures, and forest areas respectively.

3. The erodibility of soil (K) depends on many physical properties, such as particle size and cohesion, proportion of organic material, aggregate sizes and permeability. Fortunately, these micro-properties of soil can be mapped to the most common classes of soil types (such as sandy, loamy etc.) via standard estimates. For the area under study, soil type maps exist from which a K mapping can be derived using the estimates shown in Tab. 1 (after Schwertmann et al. 1990, Fleck 1995): All of the USLE-parameters considered so far are stable enough in time to allow incorporation into a model for the entire Holocene (except for C) and can be represented adequately on a landscape scale level. The protective measurements factor (P) is of no value for the application shown here and will be kept constant (P=1), as it is variable on a very small scale and there is no way to reliably estimate its impact in the past.

soil type	***K***
sand	0.100
weakly loamy	0.150
loamy sand	0.200
very loamy sand	0.250-0.300
sandy loam	0.400
loam	0.500
loamy clay	0.350-0.400
clay	0.300
marshy ground	0.020

Tab. 1: soil types and associated K values for the "Havelland" study area.

4. The LS factor is calculated based on parameters derived from a digital elevation model (DEM) of the study area. Building a DEM that reflects the natural topography with adequate precision is something of a challenge. The only available elevation data of sufficient quality for the Havelland is a contour line paper map on a scale of 1:10,000. Using data points derived from contour lines for DEM interpolation has the significant drawback that the data points are not evenly distributed but instead form linear patterns in the data point space. This usually shows through as terrace-like structures in the resultant DEM and causes interpolation algorithms to produce overshoots in areas where contour lines have wide spacing (i.e. flat terrain). For the USPED model to be applied successfully, the DEM must be smooth, centimetre-precise and free of artificial patterns. Fortunately, this can be achieved using an advanced algorithm which is based on splines and can be parameterized to take particularities of data sources and terrain into account (Regularized Splines with Tension: see Neteler and Mitasova 2002:chapter 7.4, for specification and example usage of the algorithm).

An Archaeological Study Case

The Havelland is a typical landscape in North-eastern Germany which is located west to the urban area of Berlin (Fig. 1). Until modern times, the landscape's appearance was characterized by a dense network of streams that made the region a much-frequented passage way and established its status as an important centre of prehistoric settlement activity from the Neolithic to the Iron Age (unfortunately, comprehensive archaeological literature on the region is sparse at best; for those readers who can read German, Buck 2000 might be a useful reference).

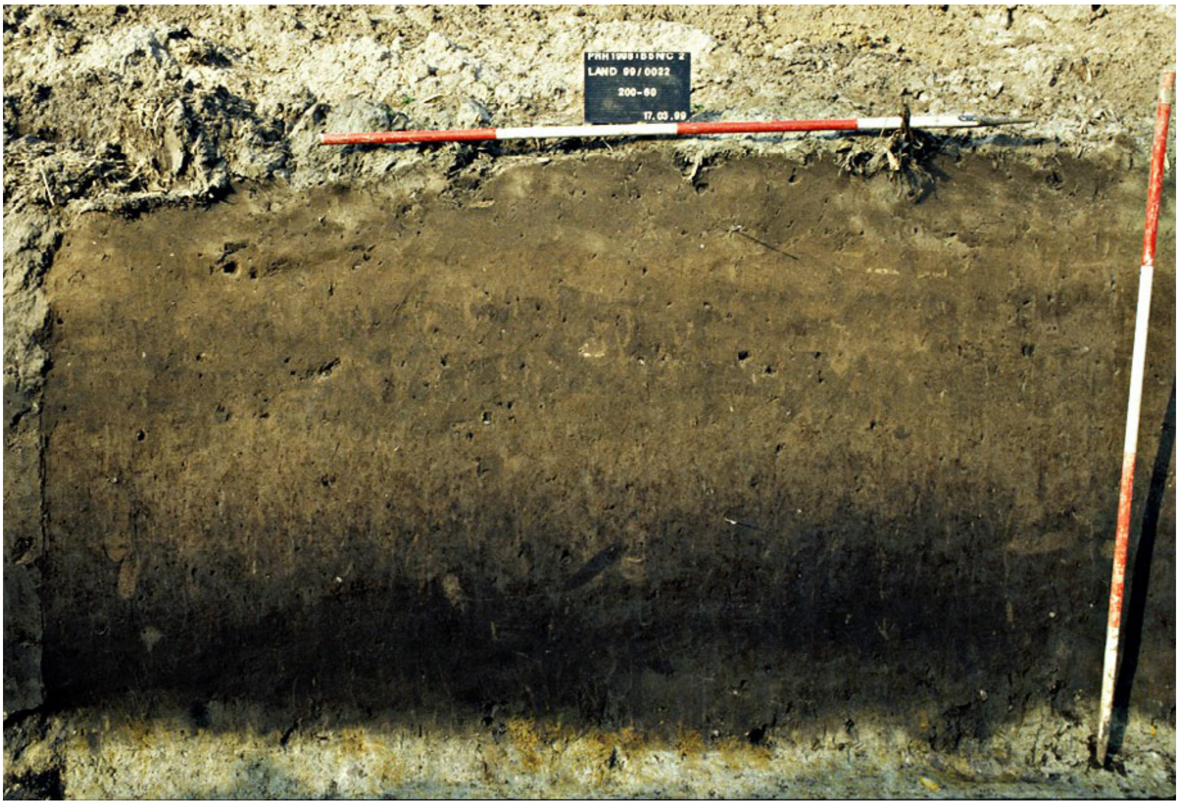

Fig. 4: Stratigraphic cross-section of Dyrotz 37 (courtesy of L.A.N.D. ltd.).

During the first three decades following World War II, the communist regime of Eastern Germany re-organized agriculture on a nation-wide scale. The grand new scheme was to agglomerate the historical mosaic of small privately-owned patches of land into a much smaller number of large colchose-style farms that could be operated with heavy industrial equipment while at the same time the ground water level was systematically reduced by forcing the smaller streams into collective concrete beds. This finalized the ruin of the historical landscape which subsequently gave way to the modern, minimized topography which is composed of broad and gentle slopes that are predominantly used for growing crops (Fig. 2). As a case study for the local impact of the global erosion/deposition pattern, we will take a look at the prehistoric settlement site of Dyrotz 37. The site is situated in the eastern part of the Havelland with the biggest part of the excavated area on the upper parts of the slope and a small section in the west extending over the foot of the slope and into the peaty soil below. Artefacts indicate that several prehistoric settlements have been erected on the site over a period of approximately 4,500 years: 1. Middle Neolithic (ca. 4600-4300 BC), 2. Late Neolithic (ca. 3500-3100 BC), 3. Late Bronze Age (ca. 1300-1100 BC), 4. Iron Age (ca. 550 BC-0 AD), 5. Germanic Age (ca. 0 AD-500 AD). Fig. 4 shows the stratigraphic situation in those parts of the site that were covered under soil deposits: several colluvial layers can be distinguished by their darker shades. Undisturbed, natural soil layers of lighter shade in-between them are evidence of prolonged periods without settlement activity on the site and its immediate neighbourhood. The features in the western part of the excavated area lay buried under more than 2 metres of colluvial depositions and were accordingly well preserved (Fig. 5).

Fig. 5: Some well-preserved archaeological features of Dyrotz 37: Left: Neolithic well: right: wooden posts of a Bronze Age palisade (courtesy of L.A.N.D. ltd.).

Roughly two thirds of the excavated area is situated up-hill where erosion has been pre-dominant and has essentially erased all of the prehistoric layers. The bottom parts of settlement pits were essentially the only surviving archaeological features in this area. In ignorance of the geomorphological situation, the site's importance was well underestimated and the resources allocated to its excavation were insufficient leading to a great loss of valuable archaeological information. It should be noted that the erosion/deposition model depicted in Fig. 6 has been colour-coded for easy recognition of erosion/deposition patterns. In the natural landscape, the "steepness" of the slope on which the site is located is around 2 degrees and hardly recognizable at all. Even this small gradient, however, does make a decisive difference for the site's stratigraphic structure and the level of preservation of its archaeological features. The USPED-based model accurately predicts the depositional pattern of the site. A map like that shown in Fig. 3 will greatly support landscape-scale decision-making and the planning of archaeological excavations in the future. Dyrotz 37 is thus a strong case for the importance of a firm understanding of landscape evolution even in a seemingly featureless landscape.

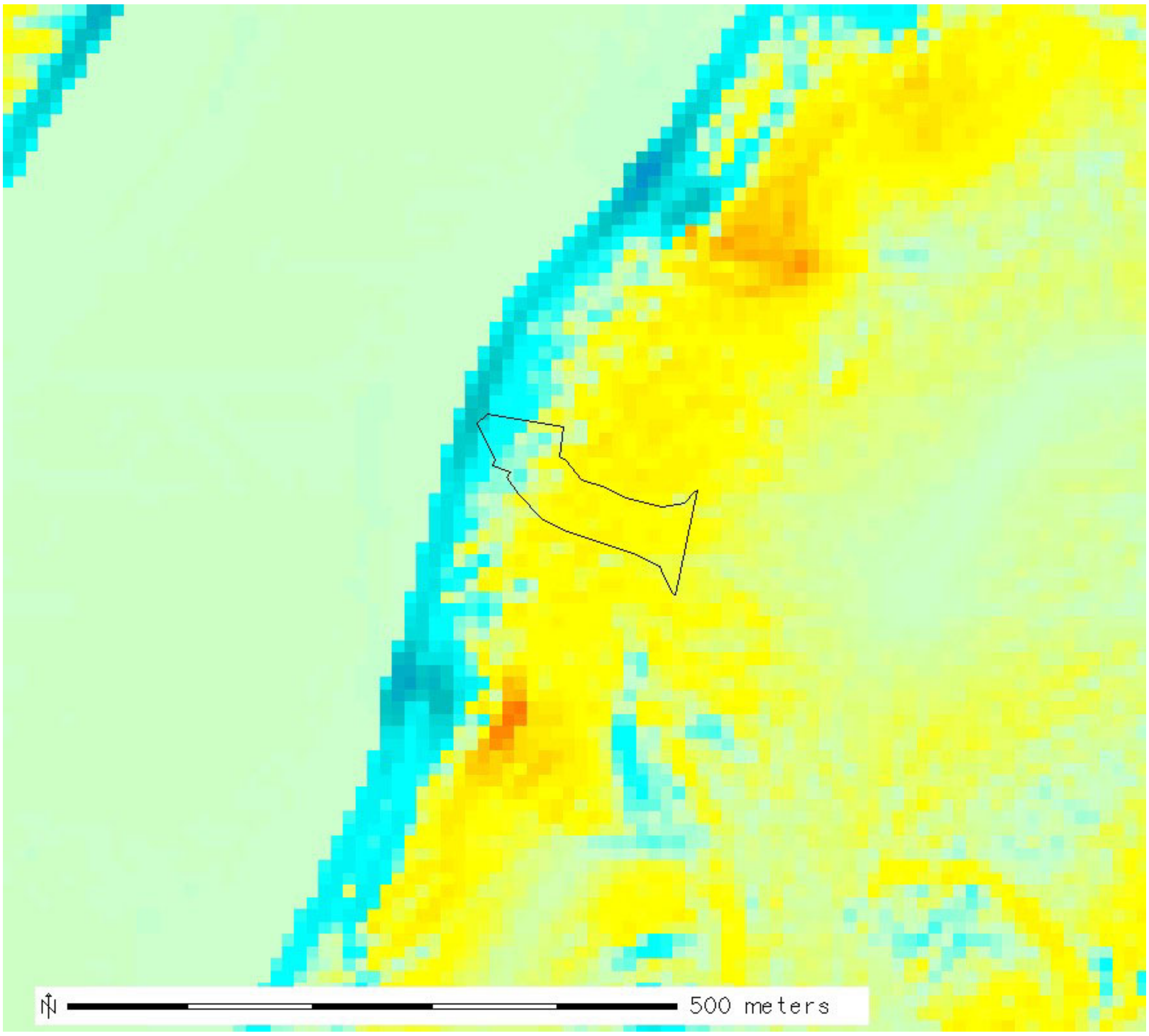

Fig. 6: USPED-based erosion/deposition model of the archaeological excavation site "Dyrotz 37" (lower right, corner, red outline) and its surroundings. Colour codes: see Fig. 3.

The USPED-based model as presented in Figs. 5 and 6 does, of course, lack a precise mapping from colour codes to actual erosion/deposition volumes. At the moment, all that can be said is that saturated blue indicates "strong deposition" while saturated red indicates "strong erosion". In the case of Dyrotz 37, the individual depositional layers are up to 1.5 meters in height. It is not possible to state precisely how long it took them to grow to that height as soil erosion is not a process of continuous growth but rather the cumulative result of several catastrophic events. The chronological determination of each erosion/deposition event and the accurate quantification of its strength requires geo-archaeological data of a quality that the entire study area presently lacks. Bork et al. (1998) have more precise estimates for North-eastern Germany that indicate a total vertical change of relief of about 0.5 m. This quantification, however, represents a spatially averaged value that includes those areas which have never been claimed by prehistoric farming. The immediate neighbourhoods of prehistoric settlements form hotspots of soil erosion processes that represent local maxima of erosion/deposition rates. For future work on the subject, many more site stratigraphies will have to be examined before a statistically valid relationship between USPED-calculated values and actual soil volumes can be established.

Results

Erosion and deposition are factors of primary importance when trying to predict the potential locations of well-preserved archaeological sites in the landscape.

USPED is a robust geo-physical model that precisely determines the spatial distribution of soil erosion and deposition based on the landscape's topographic properties. The rate of erosion/deposition is estimated using the standard USLE parameters which can in turn be derived from a number of sources. In applications for which prediction of the spatial distribution without consideration of rates is adequate, USPED can produce usable results from a high-quality digital elevation model (DEM) alone. If no better sources are available, a DEM of sufficient quality, even for areas with flat relief, can be calculated from digitized contour lines using a properly parameterized version of the Regularized Splines with Tension (RST) algorithm.

Both USPED and the RST algorithm can be used from within the framework of the freely available geographic information system GRASS (see GRASS GIS 2003). No over-priced commercial software or data needs to be employed to get the best possible results.

The method described in this document yields valid results only for a restricted class of landscape types where erosion and deposition caused by run-off are the dominant processes. The model can thus be applied to vast areas of the Central and Northern European Lowlands from the Netherlands to Poland. In other types of landscapes, Aeolian depositions, stream meandering, littoral processes etc. may be of importance. Modelling geomorphological evolution in more complex settings is possible using a process-based erosion model, such as the CHILD model (see Zeidler and Isaacson 2001).

It should be stated, that the results presented in this paper would probably not have been possible to achieve even a few years ago. Earlier studies with similar aims (e.g. Verhagen 1996, Saile 2001) suffered from a lack of publicly available, efficient models as well as geo-archaeological data. It is owing to the efforts of a scientific community that incorporates experts from the fields of archaeology, geomorphology, geophysics as well as mathematics and computer sciences and the growing support for freely available program code, documentation and data on the internet, that the research presented in this paper has become possible. The author would therefore like to thank all the supporters of free software and information on the internet.

References

BORK, H.-R., 1988. Bodenerosion und Umwelt. Verlauf, Ursachen und Folgen der mittelalterlichen und neuzeitlichen Bodenerosion, Braunschweig.

BORK, H.-R, BORK, H., DALCHOW, C., FAUST, B., PIORR, H.-P. and SCHATZ, T., 1998. Landschaftsentwicklung in Mitteleuropa - Wirkungen des Menschen auf Landschaften. Gotha, Stuttgart.

BUCK, D.W., 2000. Hügelgräber-, Urnenfelder- und ältere Hallstattzeit. In: Potsdam, Brandenburg und das Havelland. *Führer zu archäologischen Denkmälern in Deutschland* 37, Stuttgart:53-58.

DAVIDSON, D.A., 1985. Geomorphology and Archaeology. In Rapp, G. and Gifford, J.A., (eds.), *Archaeological Geology,* New Haven, London:25-55.

ELLISON, W.D., 1944. Studies of raindrop erosion. *Agric. Eng.* 25:131-181.

FISCHER-ZUIJKOV, U., 1998. Das “Schwarze Kolluvium” - Auswirkungen der ur- und frühgeschichtlichen Landnutzung auf die

Umweltbedingungen in der Uckermark. In *Beiträge zum Oderprojekt* 5, Berlin:99-102.
FLECK, W., 1995. Ermittlung von K-Faktoren - Reichsbodenschätzung und Bodenbestandsaufnahme. *Handbuch Boden, Materialien zum Bodenschutz*, Band 4, Karlsruhe:56-65 (http://www.uvm.baden-wuerttemberg.de/bofaweb/print/mzb04.pdf).
GRASS GIS 2003. Geographical Resources Analysis Support System, Version 5 (http://www.geog.uni-hannover.de/grass/index.html).
HOLLIDAY, V.T., 1992. Soil Formation, Time and Archaeology. In Holliday, V.T. (ed.), *Soils in Archaeology - Landscape Evolution and Human Occupation,* Washington, London:101-188.
JÄGER, K.D. and LOZEK, V., 1977. Indications of Holocene stratigraphy concerning the changing natural structure and metabolism of landscape in consequence of human impact. In *Proceedings of Working Session of Commission on Holocene - INQUA (Eurosiberian Subcommission)*, Tatranska Lomnica, Bratislava 1976:93-110.
JÄGER, K.D., 1996. Umweltbedingungen und Umweltwirksamkeit der neolithischen Besiedlung. In Preuss, J. (ed.), *Das Neolithikum in Mitteleuropa - Kulturen-Wirtschaft-Umwelt vom 6. bis 3. Jahrtausend v.u.Z. Übersichten zum Stand der Forschung*, Band 1/1, Weißbach 1998:25-33.
KRAUSKOPF, C. and PASDA, C., 1999. Aufwehung, Umbildung, Zerstörung - Zur Entwicklung der Dünen im Brauther Urstromtal zwischen Cottbus und Forst. *Archäologisches Korrespondenzblatt* 29:289-298.
MITASOVA, H., BROWN, W.M., JOHNSTON, D. and MITAS L., 1996. GIS Tools for Erosion/Deposition Modeling and Multidimensional Visualization. Part II: Unit Stream Power-Based Erosion/Deposition Modeling, and Enhanced Dynamic Visualization. *Report for USA CERL,* Urbana-Champaign (http://skagit.meas.ncsu.edu/~helena/gmslab/reports/rep2.ps).
MITASOVA, H. and MITAS, L., 1999. Erosion/deposition modeling with USPED using GIS (http://skagit.meas.ncsu.edu/helena/gmslab).
MITASOVA, H., BROWN, W.M., HOHMANN, M. and WARREN, S., 2001. Using Soil Erosion Modeling for Improved Conservation Planning: A GIS-based Tutorial. GMSLab and USA CERL (http://skagit.meas.ncsu.edu/~helena/gmslab/reports/CerlErosionTutorial/denix/denixstart.html).
MORGAN, P.C., QUINTON, J.N., SMITH, R. E., GOVERS, G., POESEN, J.W.A., AUERSWALD, K., CHISCI, G., TORRI, D., STYCZEN, M.E. and FOLLY, A.J.V., 1998. The European Soil Erosion Model (EUROSEM): documentation and user guide Version 3.6. Silsoe College, Cranfield University, UK, Silsoe, Bedford.
MOORE, I.D. and BURCH, G.J., 1986. Physical basis of the length-slope factor in the universal soil loss equation. *Soil. Sci. Soc. Am. J.* 50:1294-1298.
NETELER, M. and MITASOVA, H., 2002. Open Source GIS: A GRASS GIS Approach. Boston, Dordrecht.
RENARD, K.G., FOSTER, G.R., WEESIES, G.A. and PORTER, J.P., 1991. Revised universal soil loss equation RUSLE, *USLE-EPIC-RUSLE-Wepp Bull*. 1:30-33.
ROOSE, E., 1996. Land husbandry - Components and strategy. *Food and Agriculture Organization of the United States Soils Bulletin* 70, Rome.
SAILE, T., 2001. Die Reliefenergie als innere Gültigkeitsgrenze der Fundkarte. *Germania* 79, Bd.1:93-120.
SANDOR, J.A., 1992. Long-term Effects of Prehistoric Agriculture on Soils: Examples from New Mexiko and Peru. In Holliday, V.T. (ed.), *Soils in Archaeology - Landscape Evolution and Human Occupation,* Washington, London:217-246.
SCHATZ, T., 2000. Untersuchungen zur holozänen Landschaftsentwicklung Nordostdeutschlands. *ZALF Bericht* Nr. 41, Müncheberg.
SCHWERTMANN, U., VOGEL, W. and KAINZ, M., 1990. Bodenerosion durch Wasser. Vorhersage des Abtrags und Bewertung von Gegenmaßnahmen. 2nd ed., Stuttgart.
SEMMEL, A., 1995, Bodenkundliche Hinweise auf Ackernutzung und intensive Bodenerosion um 8000 BP im Rhein-Main-Gebiet. *Archäologisches Korrespondenzblatt* 25:157-163.
TUCKER, G.E., GASPARINI, N.M., BRAS, R.R. and LANCASTER, S.T., 1999. The CHILD Model: Introduction and Roadmap. *Part 1-A of final technical report submitted to U.S. Army Corps of Engineers Construction Engineering Research Laboratory (USACERL),* Cambridge, Massachusetts (http://platte.mit.edu/~child/frintro.pdf).
VERHAGEN, P., 1996. The use of GIS for modelling ecological change and human occupation in the Middle Aguas Valley (S.E. Spain). In Kamermans, H. and Fennema, K. (eds.), *Interfacing the Past - Computer Applications and Quantitative Methods in Archaeology CAA95* Vol. II, *Analecta Praehistorica Leidensia* 28, Leiden:317-324.
WEPP, 2001. Water Erosion Prediction Project (http://opsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html).
WISCHMEIER, W.H. and SMITH, D.D., 1960. A universal soil loss estimating equation to guide conservation farm planning. *Proc. 7th Inter. Congress Soil Science Soc*, Vol. 1:418-425.
ZEIDLER, J.A. and ISAACSON, J.S., 2001. Managing Buried Archaeological Sites on Military Training Lands. In Zeidler, J.A. (ed.), *Dynamic Modeling of Landscape Evolution and Archaeological Site Distributions: A Three-Dimensional Approach,* Fort Collins:1-15 (http://www.cemml.colostate.edu/files/SEEDfinrep.pdf).